NNN05

ENGINEERING OF LARGE & DEEP ROCK CAVERNS FOR PHYSICS RESEARCH

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Pierre Duffaut, CFMR
French Committee on
Rock Mechanics

ENGINEERING OF LARGE & DEEP CAVERNS FOR PHYSICS RESEARCH

1 - examples of large caverns in France and worldwide
(shape of their sections and practice of their support)

2 - Rock Mechanics, a recent French textbook (2000-2004)

3 - theory of the hole and stress control

4 - some conclusions for a billion litres cavern
(that is a cubic hectometre = $100^3 = 10^6 = 1\ 000\ 000\ m^3$)

PART 1

examples of large caverns in France and worldwide

shape of their sections and practice of their support)

CHORANCHE natural cave, Vercors (Isère)

about 60 m wide

KNOWN NATURAL CAVES

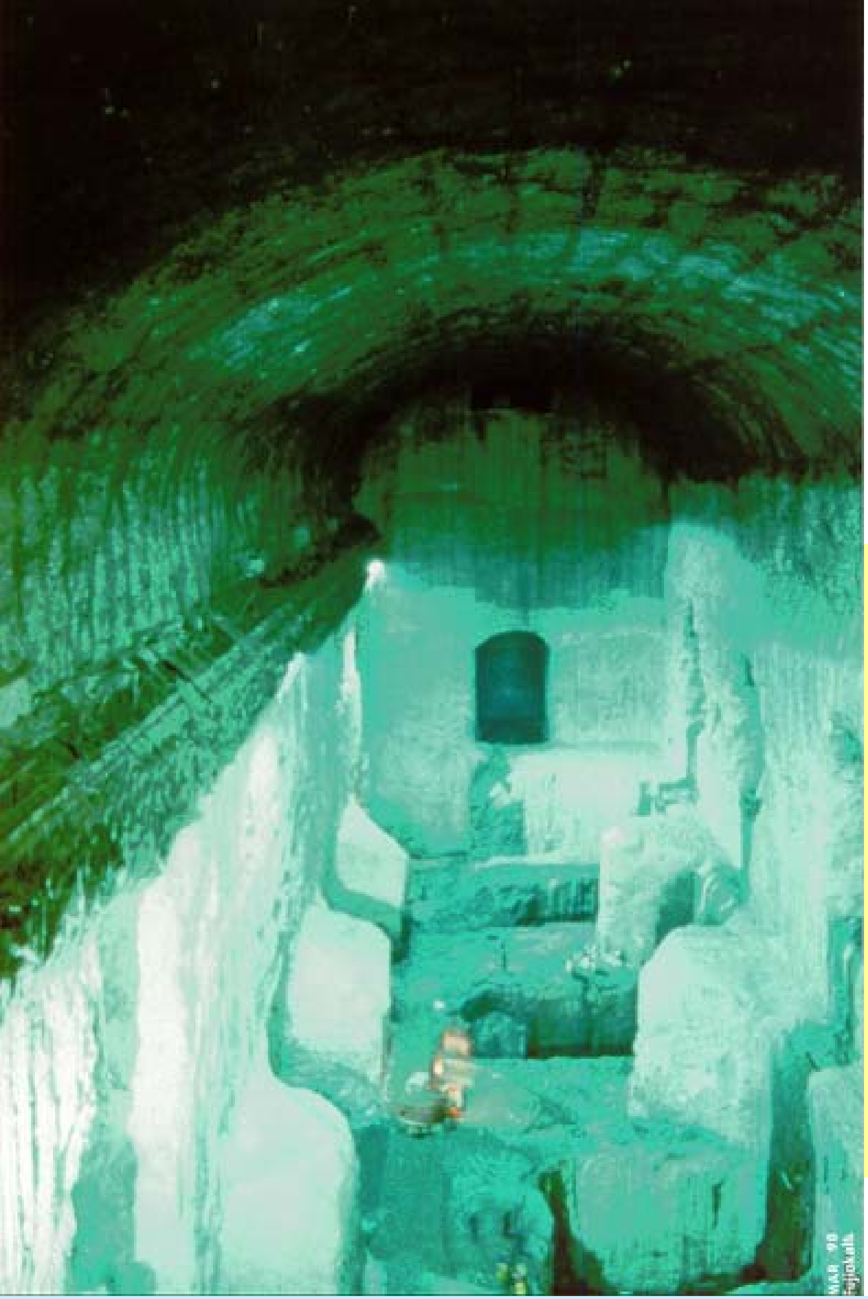
	width	height	length	remarks
Choranche (F- 38)	60	20	80	rather flat roof massive limestone, *H* 100 m
Poudrey (F- 39)	100	37	130	flat roof limestone stratum, *e* 20 m
la Verna (F- 65)	230	180	270	arched roof massive limestone, *H* 100 m
Sarawak (Malaysia)	415	100	600	lightly arched roof rather small cover about 100 m

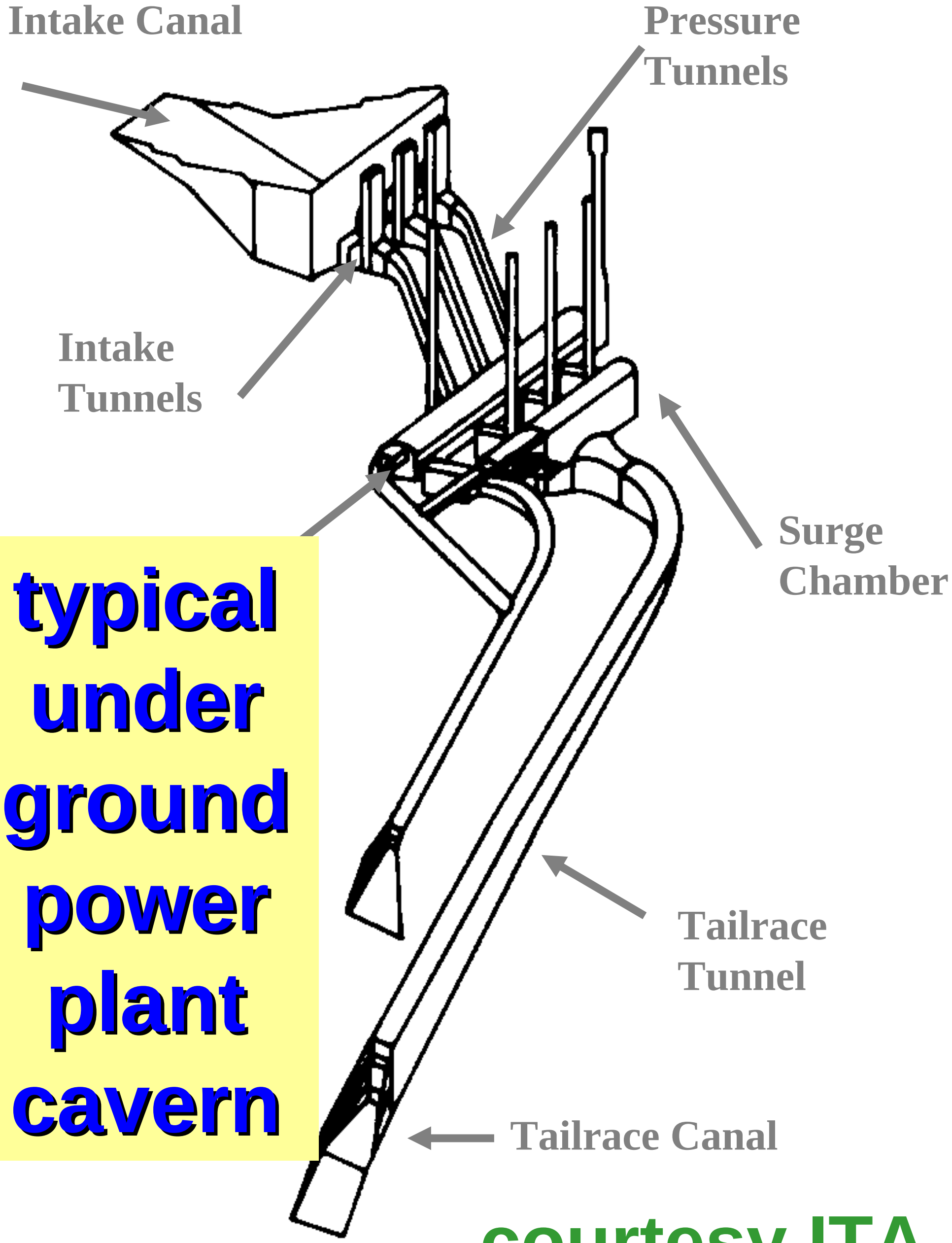
UNDERGROUND MINE CAVERNS

	width	height	length	remarks
Anjou (F- 49)	25	80	100	large vertical rooms, slate along schistosity
May sur Orne (F- 14)	30	5	100	large rooms along strata (45° and 80°)
Tytyri (Finland)	50	100	100	large tetrahedral rooms

UNDERGROUND POWER PLANTS

	width	height	length	remarks	
• hydro					
le Sautet (F 38)	35	20	35	half-circle roof	1933
Poatina (Australia)	13,7	16	50	trapezium roof stress control slots	
Grandmaison (F 38)	17	39	162	key hole, horizontal anchors	
Cirata (Indonesia)	35	49,5	253	ovoid, radial anchors	
• nuclear					
Chooz (F- 08)	18,5	37,5	41	2 caverns linked by many galleries (declassified 1992)	



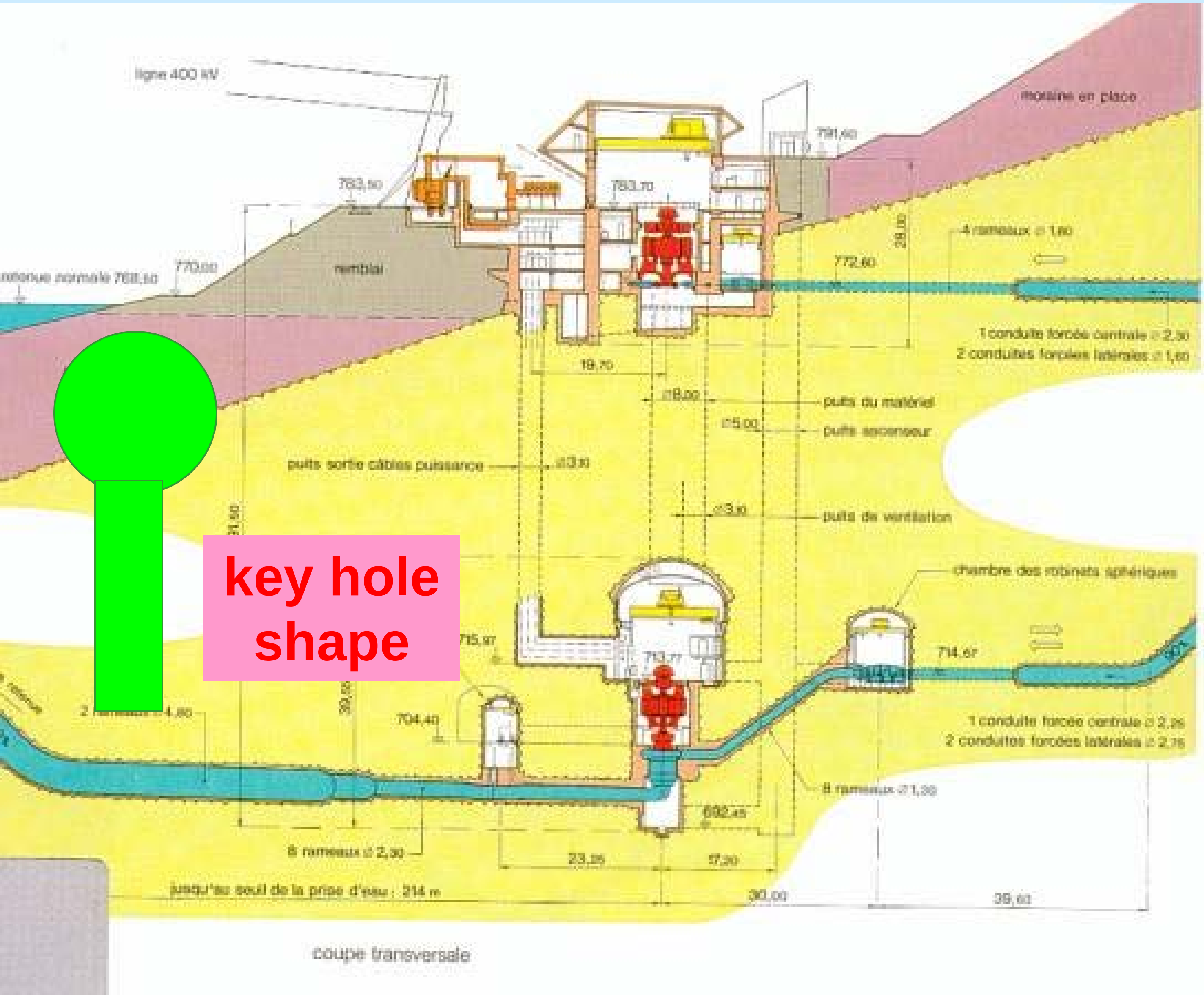


typical under ground power plant cavern

courtesy ITA

mushroom shape

GRAND'MAISON underground power plant
1800 MW



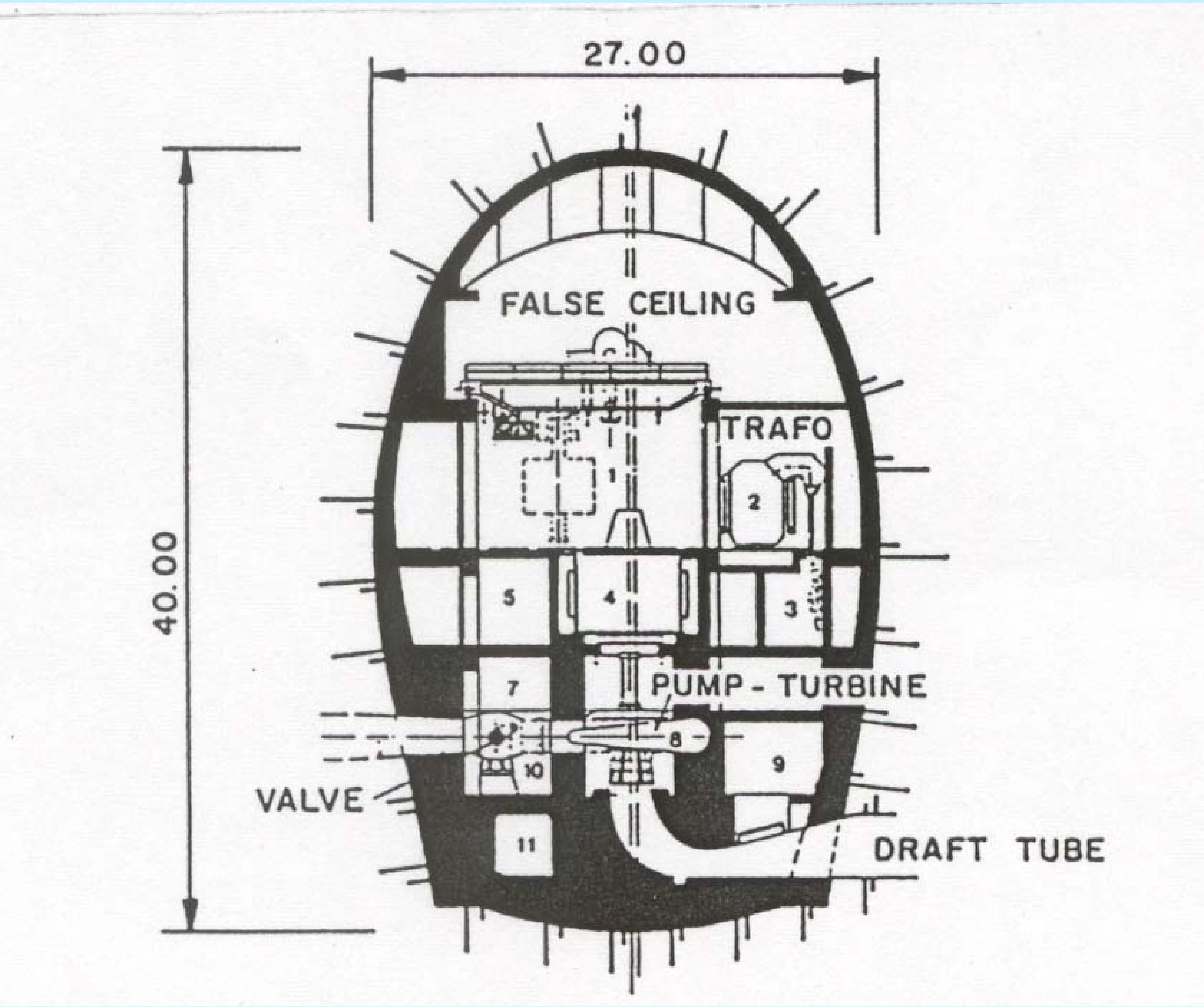
(Isère)

surface plant
6 Pelton
runners

main plant
4 Francis
runners

PORĄBKA JAR

underground power plant (POLAND)



ovoid section

support by rock bolts

all around

VARIOUS + hydrocarbon storage

	width	height	length	remarks
Banque de France (Paris)	100	3,5	108	inside a limestone formation flat room, 700 concrete pillars
Gjøvik *skating rink* (Norway)	61	25	91	arched roof ***widest unsupported civil cavern***
CERN LEP (CH Geneva)	21,4	22	85	horseshoe, half circle roof (wider spans now for LHC)

oil and gas storage caverns

Donges (F- 44)	16,5	22	115	two parallel rooms, gneiss
Porvoo (Finland)	20,5	34	500	27 rooms, gneiss
Manosque (F- 05)	80	350	600	35 very large caverns, rock salt

PARIS

BANQUE DE FRANCE gold ingots room

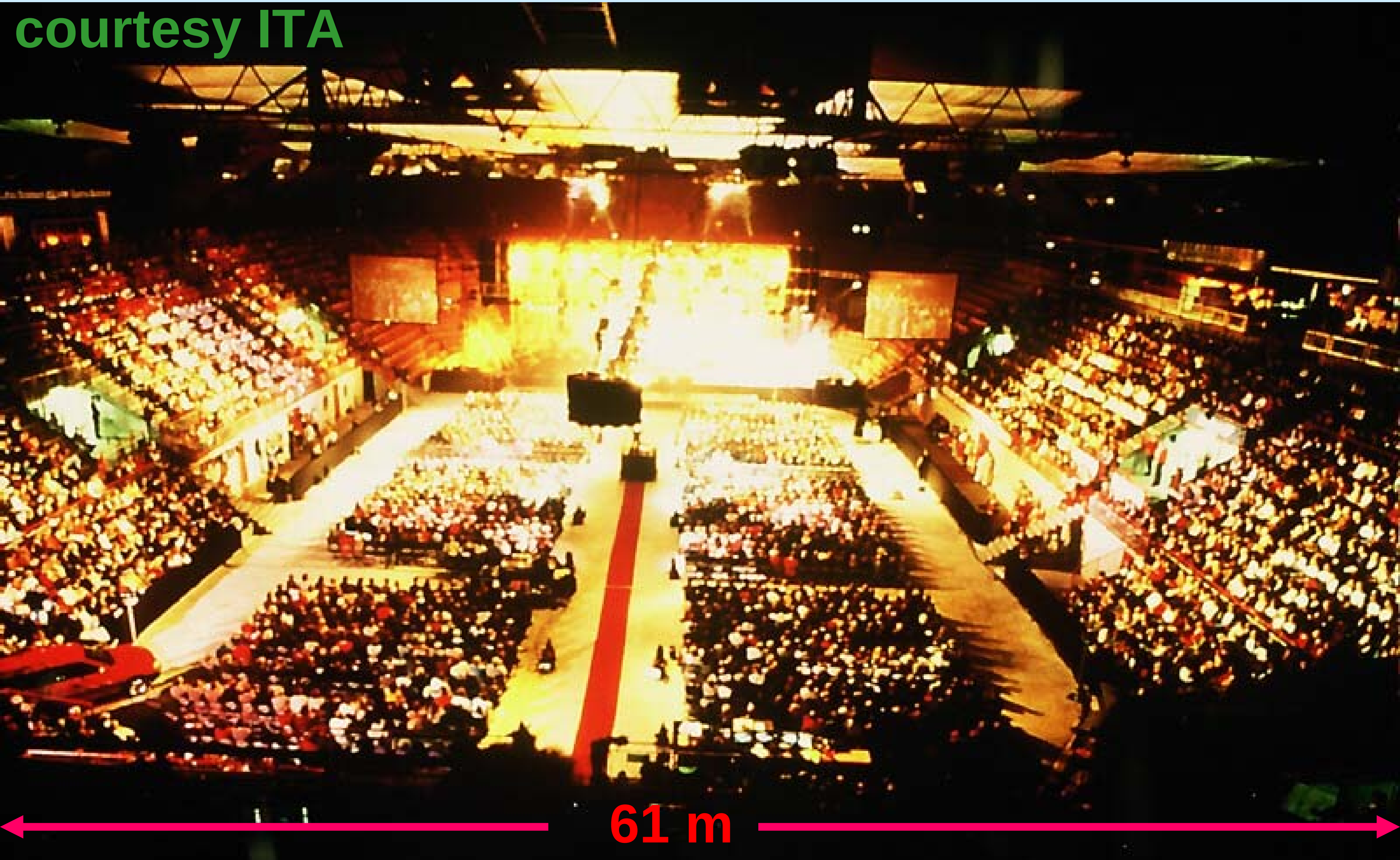
since 1924

safe room, 100 x 106 m square, 600 concrete pillars

25 m below ground, 15 m below water table

Le Point, n°1653

Gjøvik Olympic Mountain Hall (Norway)



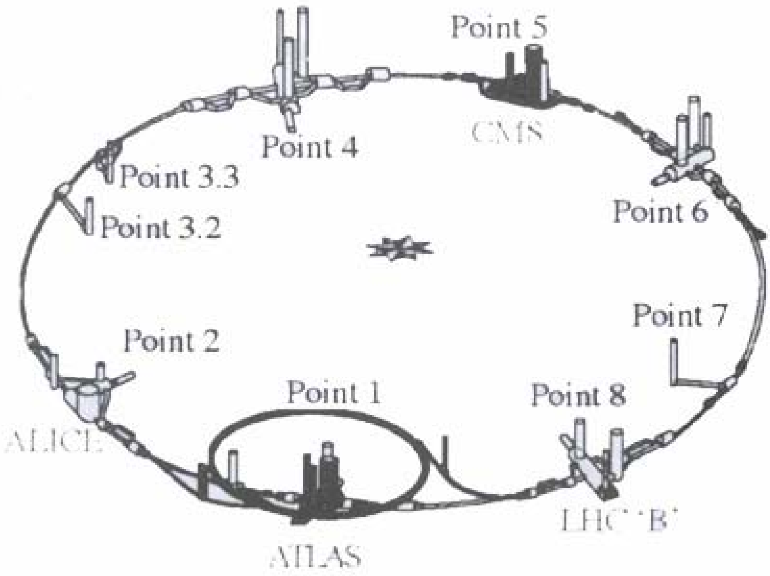
widest civil engineering cavern under 30 m granite

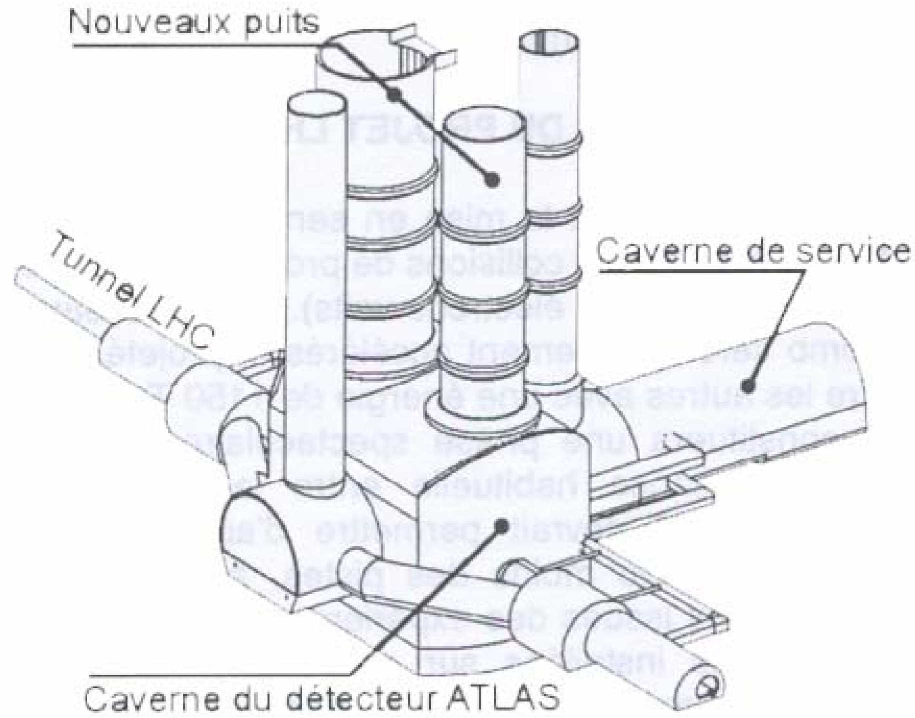
swimming pool **Helsinki (Finland) excavated in granite**

15 x 10 m GRANITE

courtesy ITA

CERN, from LEP to LHC



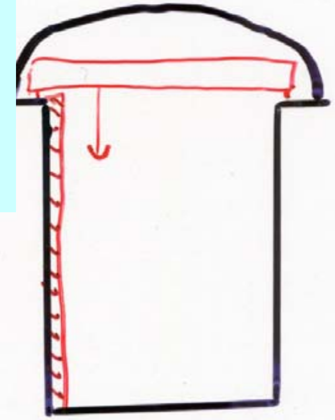


modification of points 1 & 5 : new caverns and shafts at point 1

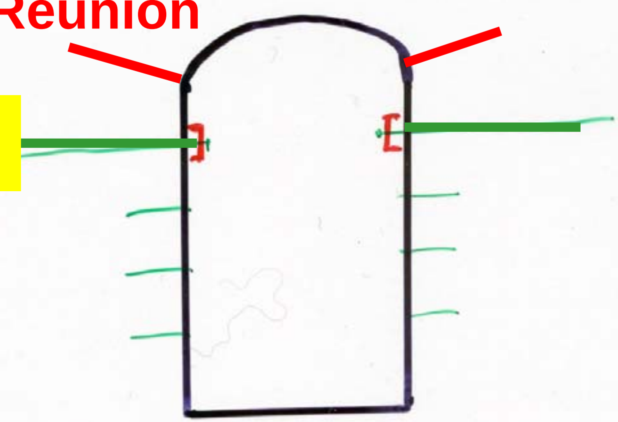
small ring SPS / large ring LEP, now turned to LHC

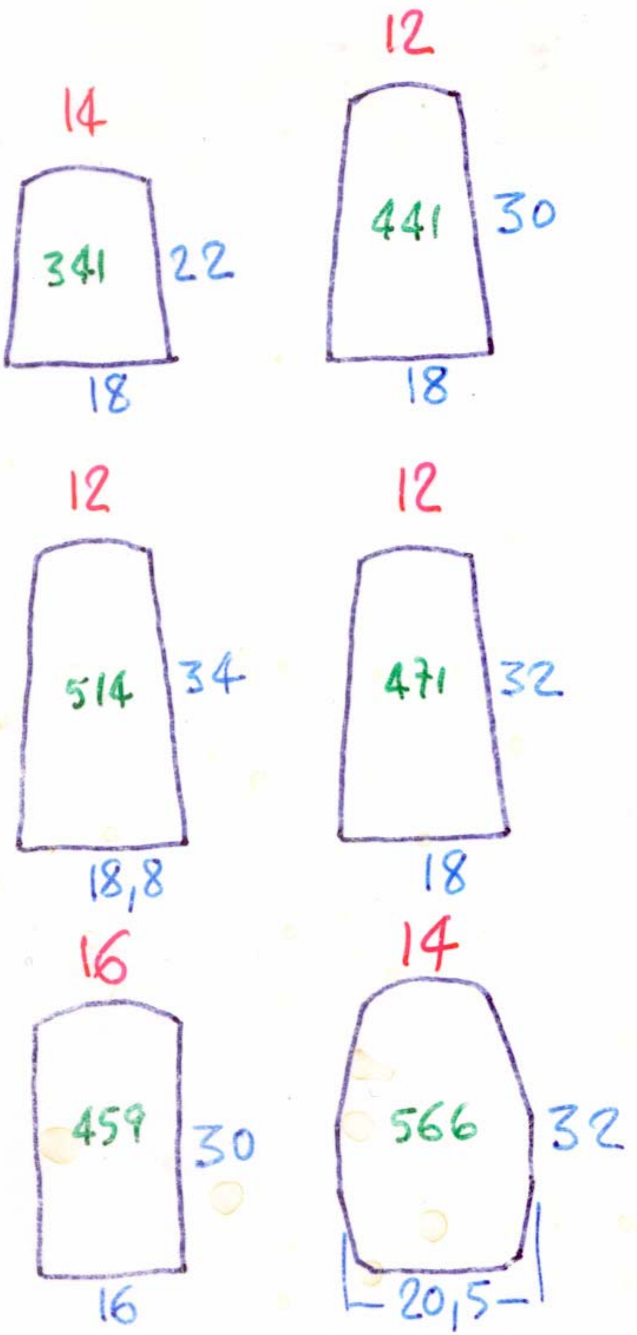
CAVERNS

hydro and thermo power plants



POATINA Australia
TAKAMAKA Réunion

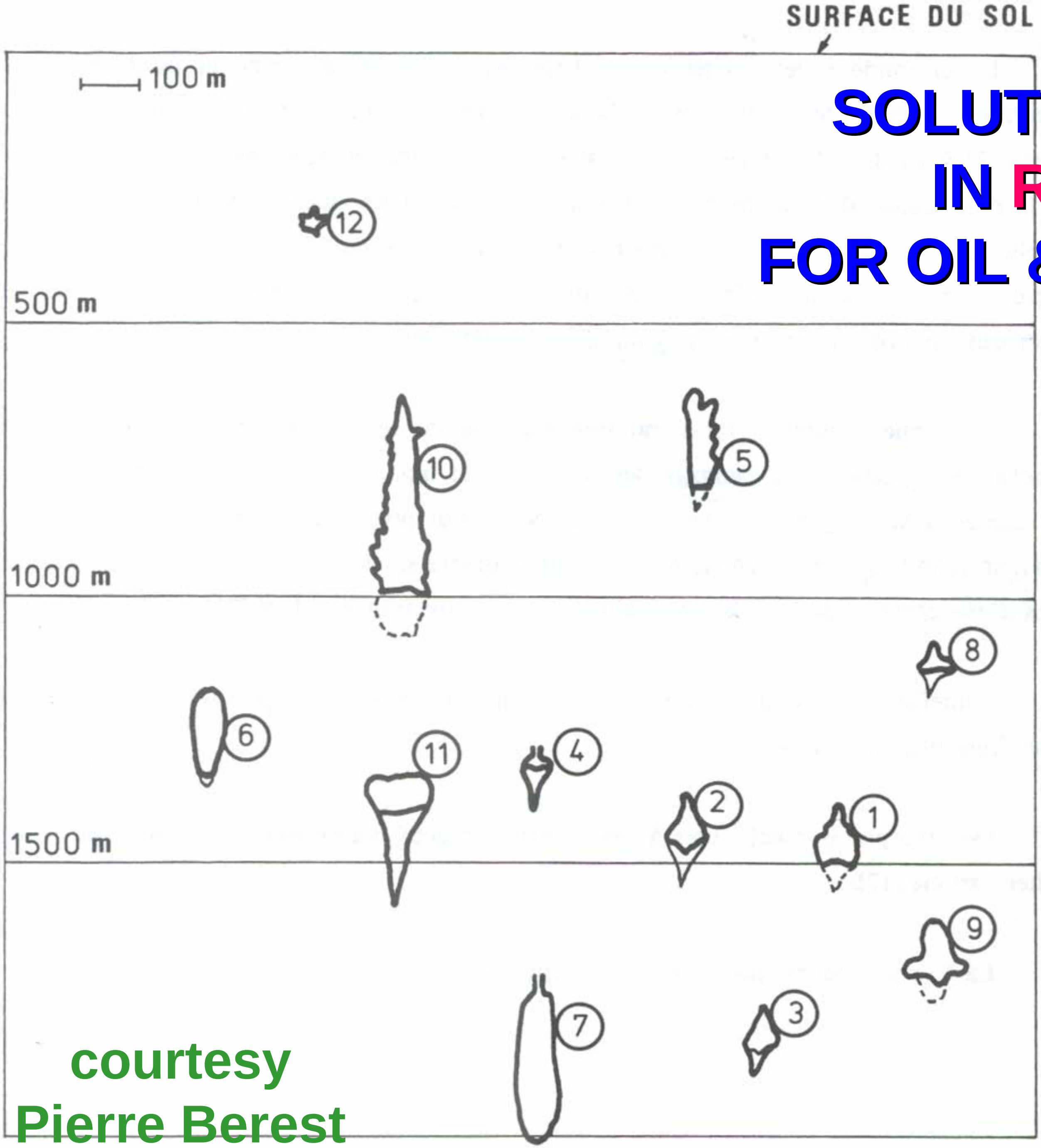




PORVOO Finland

evolution of caverns for fuel storage

SOLUTION CAVERNS IN ROCK SALT FOR OIL & GAS STORAGE



1 Tersanne

2 Etrez

7 Eminence (USA)

10 Manosque

11 Hauterives

12 Salies de Béarn

courtesy Pierre Berest

STORAGE CAVERN

8 x 12 m

in cretaceous chalk

shallow rock cover

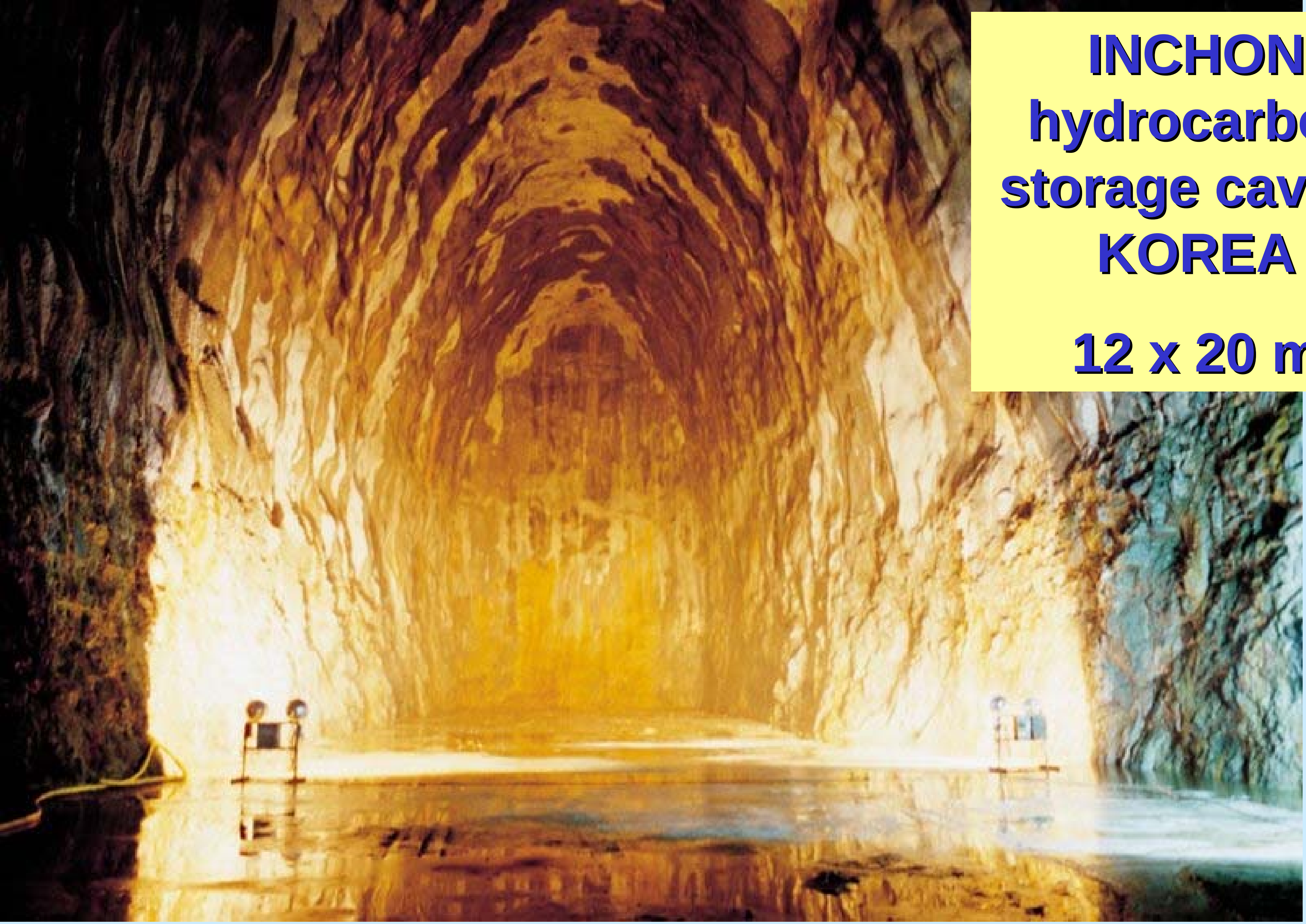
without any support

flat concrete floor

COURTESY GEOSTOCK

INCHON hydrocarbon storage cavern KOREA

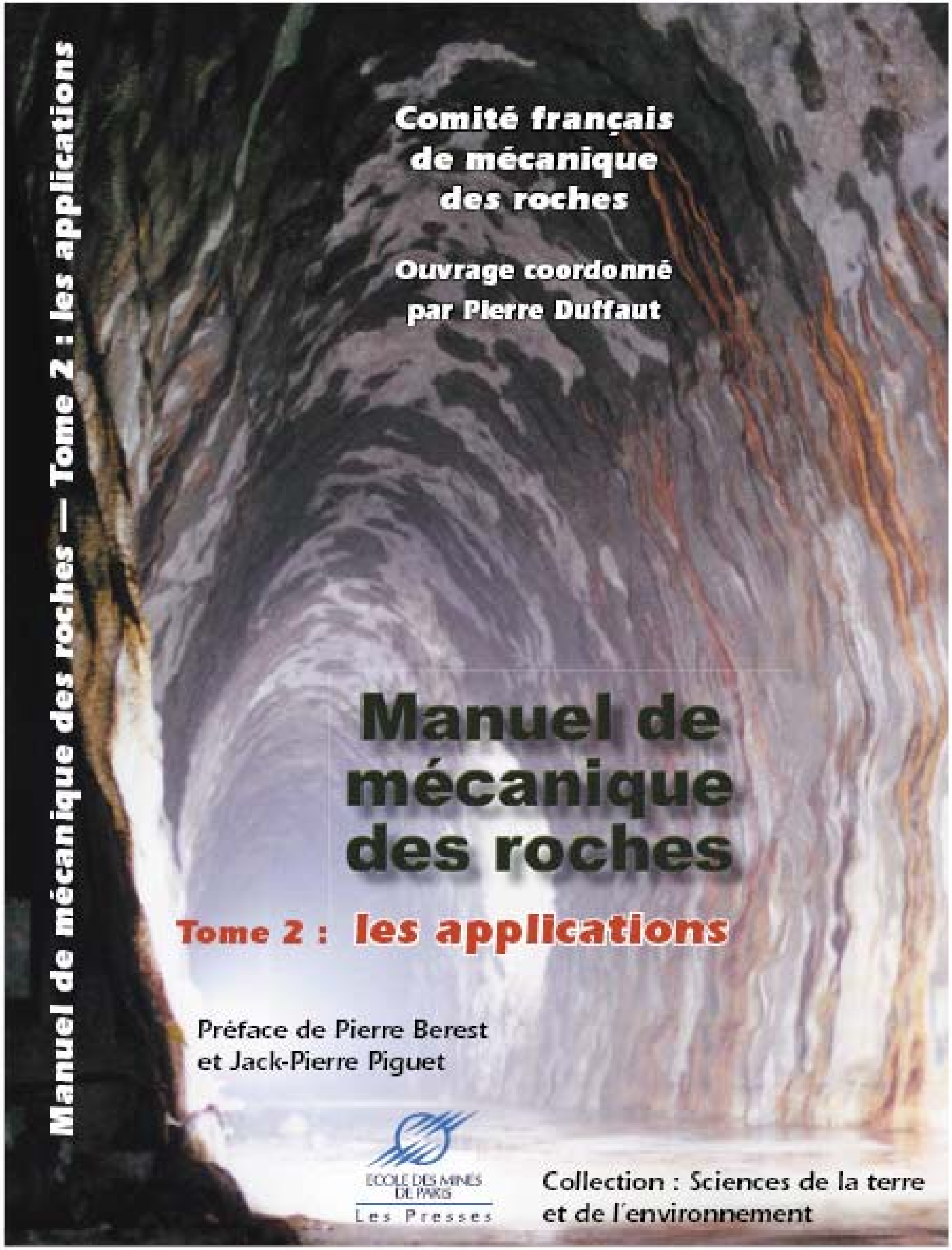
12 x 20 m



COURTESY GEOSTOCK

PART 2

- **Rock Mechanics, a recent French textbook (2000-2004)**



ROCK MECHANICS

a recent French textbook
(2000-2004)

collective work signed by
CFMR

French Committee on
Rock Mechanics

vol. 1 : *Fundamentals*
2000

vol. 2 : *Applications*
2004

« Presses de l'Ecole des Mines »
60 Boulevard Saint Michel Paris,
http://www.ensmp.fr/Presses

vol. 1: fundamentals

coordinated by Françoise Homand et Pierre Duffaut

- chapter 1 : introduction & presentation of rock mechanics
- chapter 2 : rock physics
- chapter 3 : mechanical behavior of rocks
- chapter 4 : structural description of rock masses
- chapter 5 : mechanical behavior of discontinuities
- chapter 6 : water in rocks and rock masses
- chapter 7 : stresses in rock masses and their measurements
- chapter 8 : constitutive laws
- chapter 9 : rupture
- chapter 10 : thermo-hydro-mechanical couplings
- chapter 11 : clay rocks

vol. 2: applications

coordinated by Pierre Duffaut, JL Durville, JP Piguet, JP Sarda

1 rock engineering design

2 mechanics of actions on the rock mass

3 mechanics of **underground works**

- chapter 18 shafts
- chapter 19 tunnels
- chapter 20 **caverns**
- chapter 21 underground storage
- chapter 22 storage of radioactive waste
- chapter 23 underground mining
- chapter 24 oil and gas production
- chapter 25 geothermy

4 mechanics of surface problems and works

5 perspectives

the place of GEOLOGY in geotechnics

- miners have to follow their lode, along GEOLOGY
- all underground works are embedded in GEOLOGY
- inside the ground, we are like surgeons (in man body)
- **anatomy** : which materials and structures inside?
- **physiology** : what is moving, water, heat, stress, etc?
- surface **morphology** may give useful clues

- *we have to accept the ground at it comes; it is the same with weather, along the Norwegian proverb*

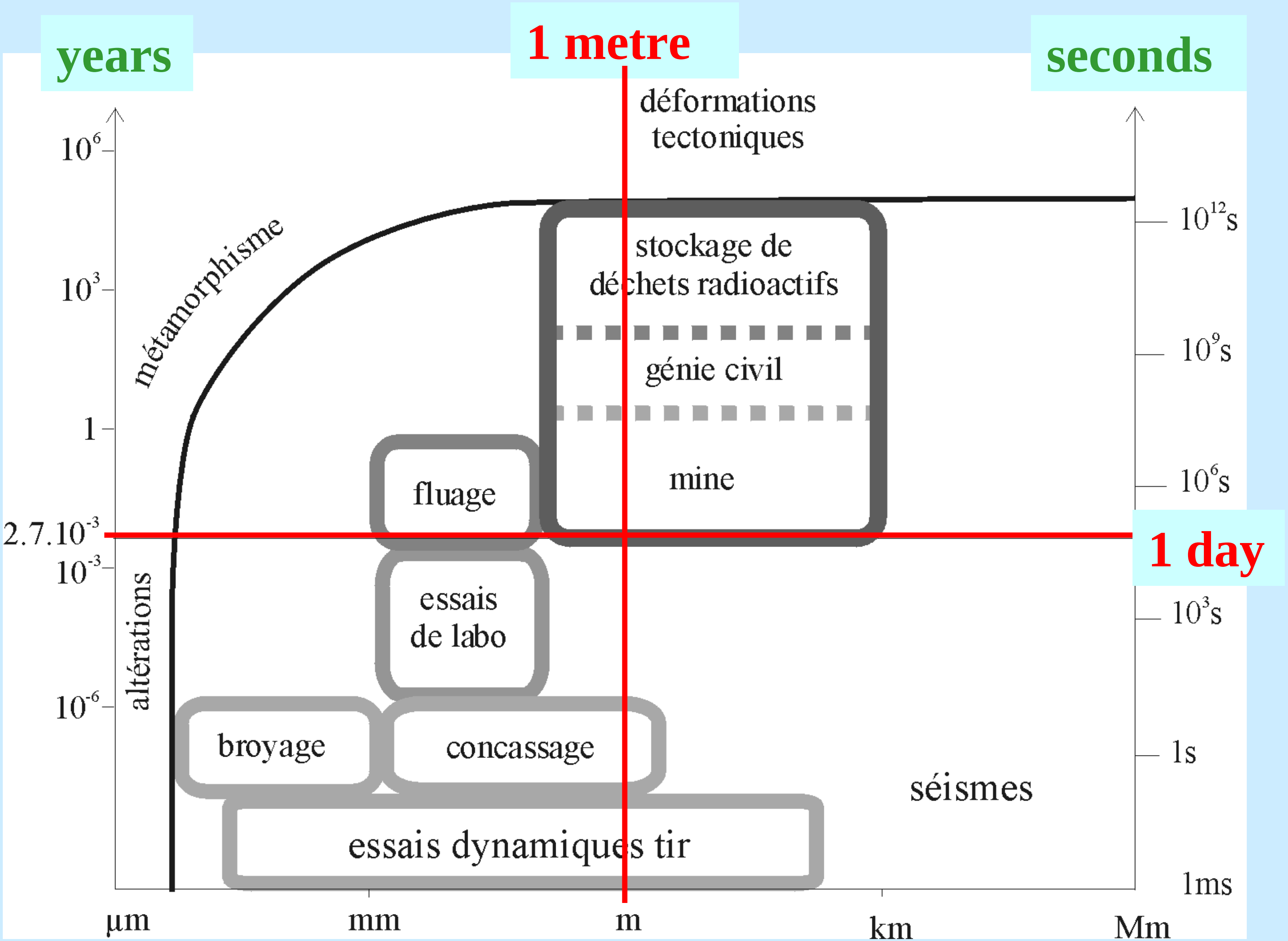
"no bad weather, only poor clothes"

"no bad ground, only poor engineering".

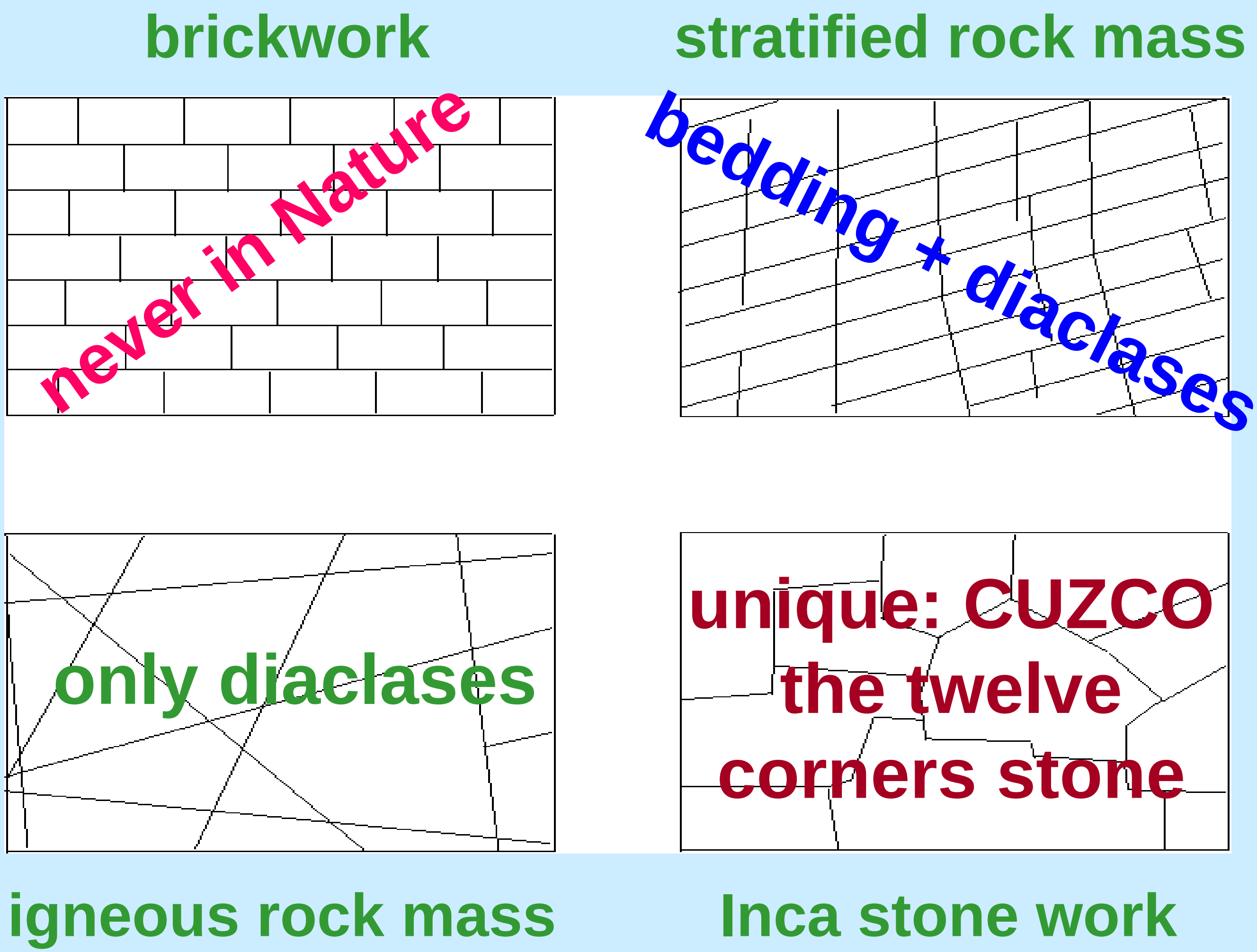
we may have to escape wrong sites and choose right ones,

we may choose right shapes and the best orientation

main scales in rock mechanics



main structures of rock masses



main structures of rock discontinuities

cubical

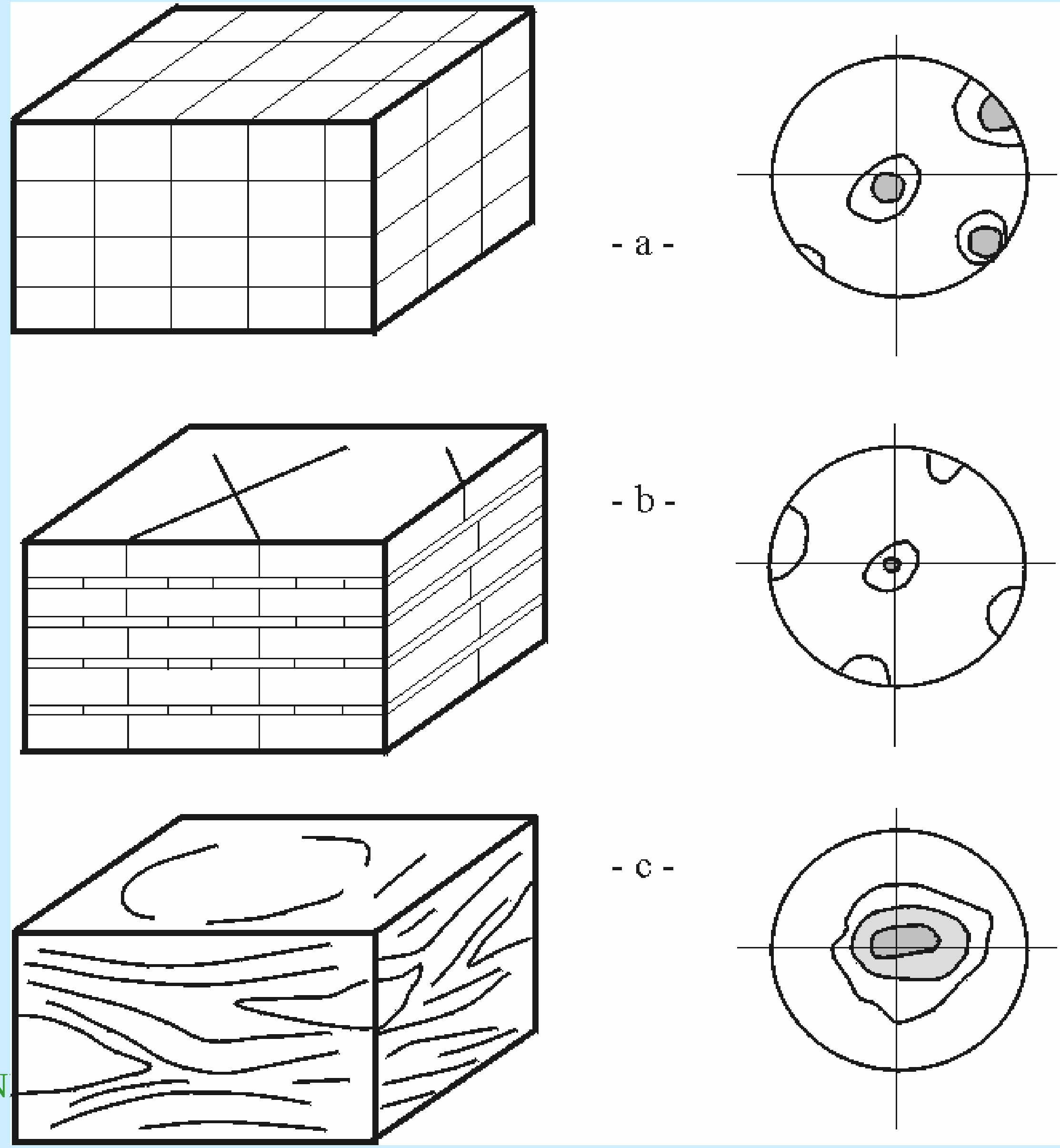
isotropic

tabular &
schistose

anisotropic

mylonitic

fault gouge



2 methods for wide tunnels

SEIKAN Undersea tunnel, JAPAN

CHANNEL Undersea tunnel, F-UK

SEIKAN TUNNEL
Japan

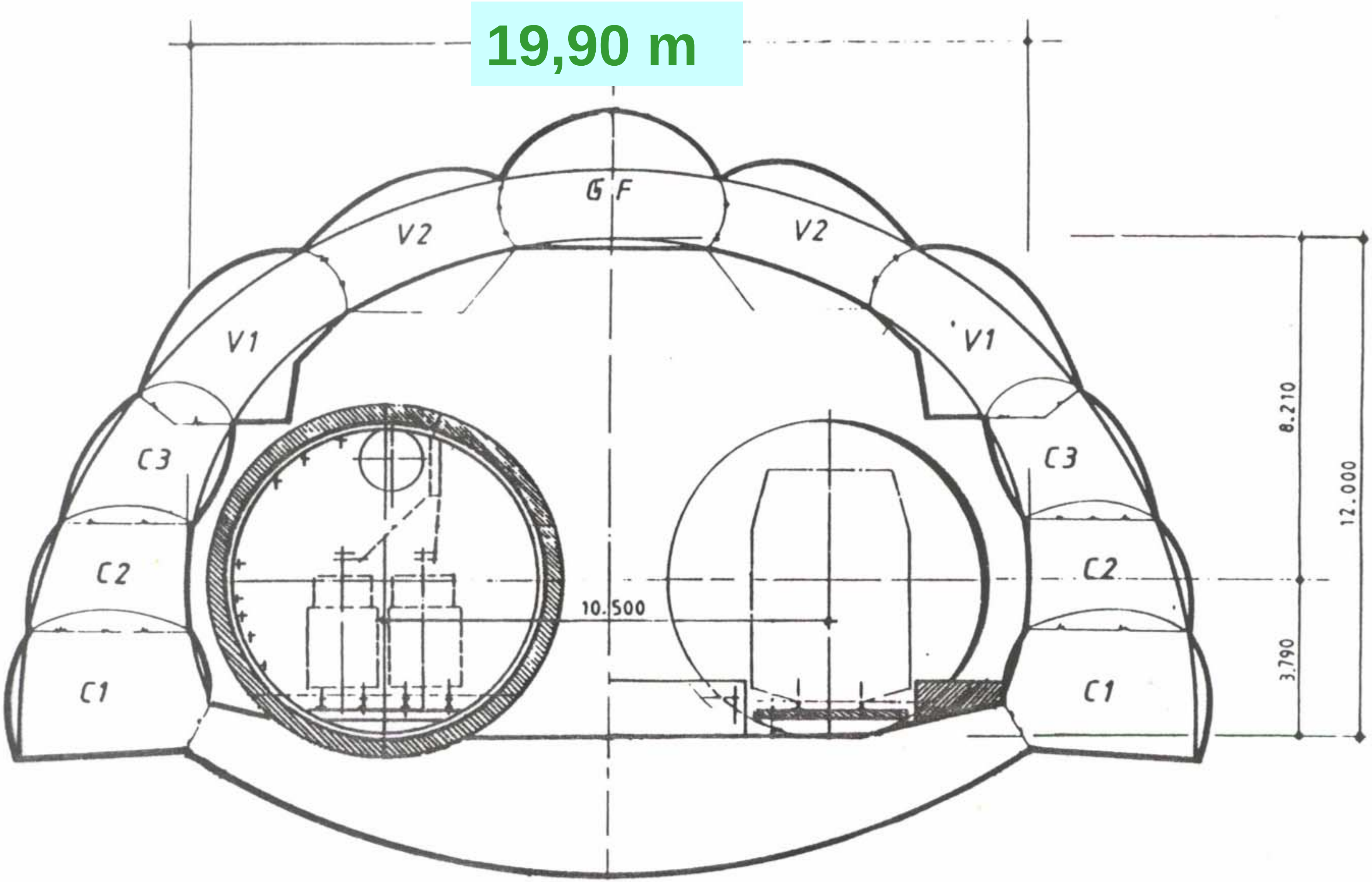
excavated by the so-called *GERMAN* method, first used at Tronquoy tunnel in France, 1803

designed for 2 standard gauge Shinkansen tracks (yet operated with 2 narrow gauge tracks)

courtesy Goichi FUKUCHI

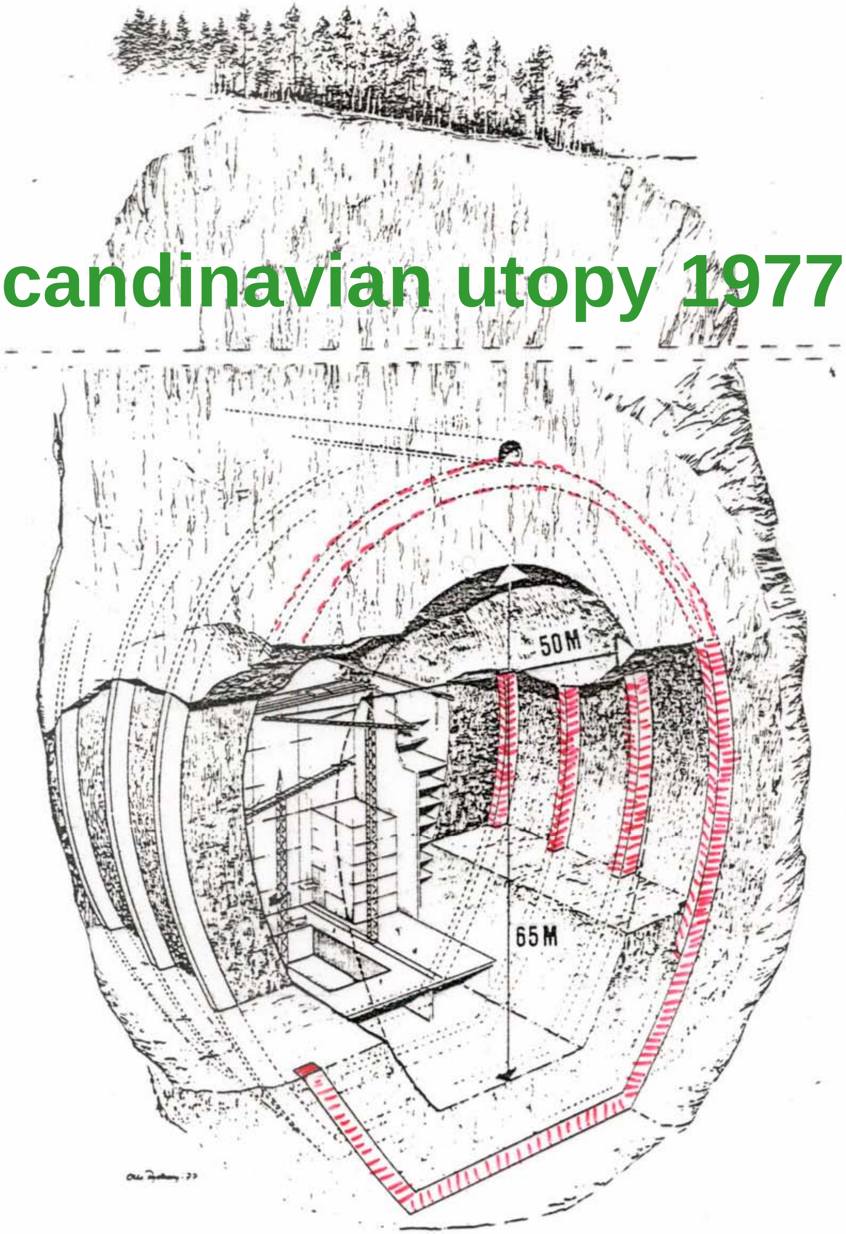
CHANNEL TUNNEL

France side crossover

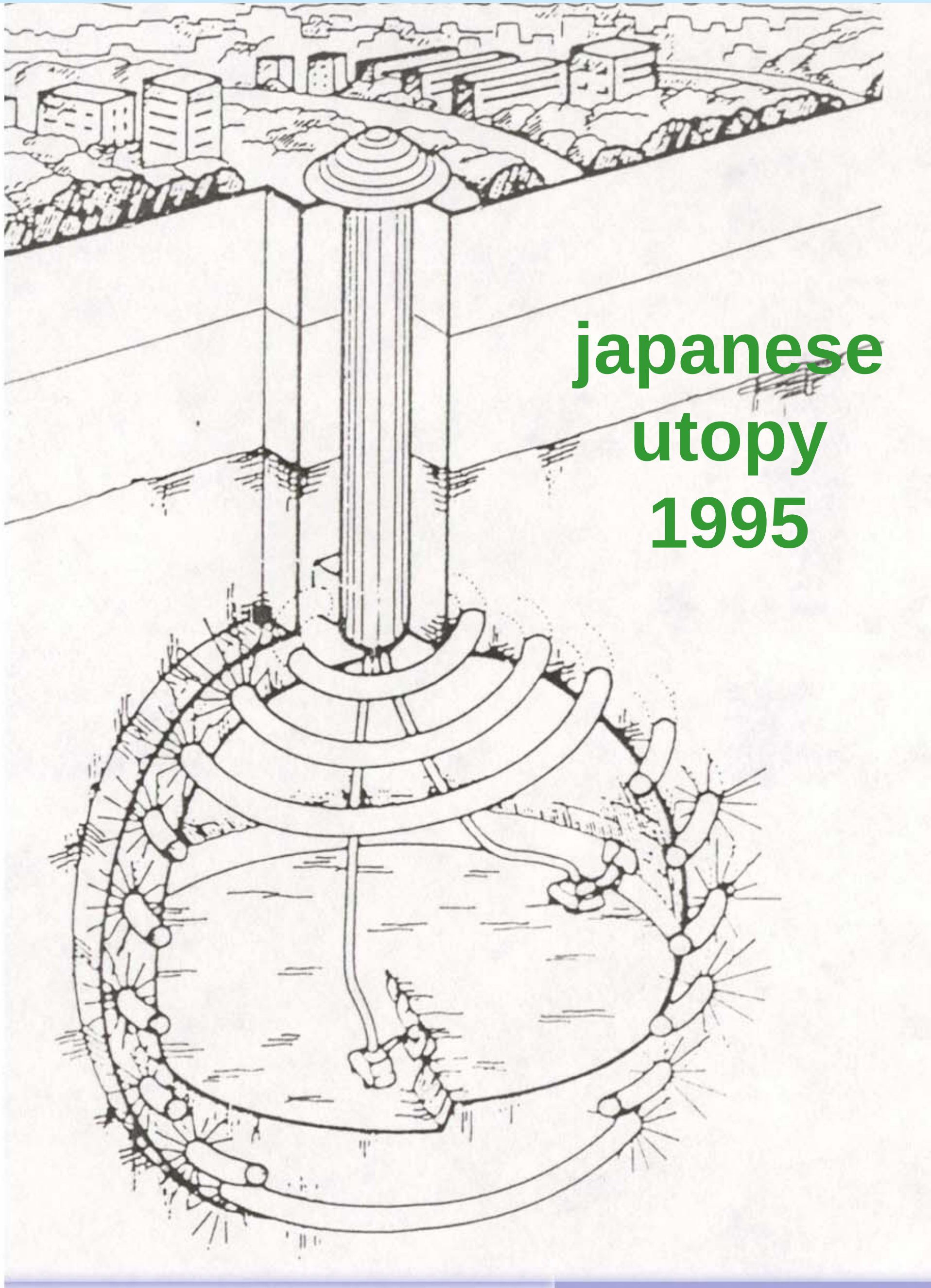


RIB in ROCK

rock reinforcement **before** excavation



scandinavian utopy 1977



japanese utopy 1995

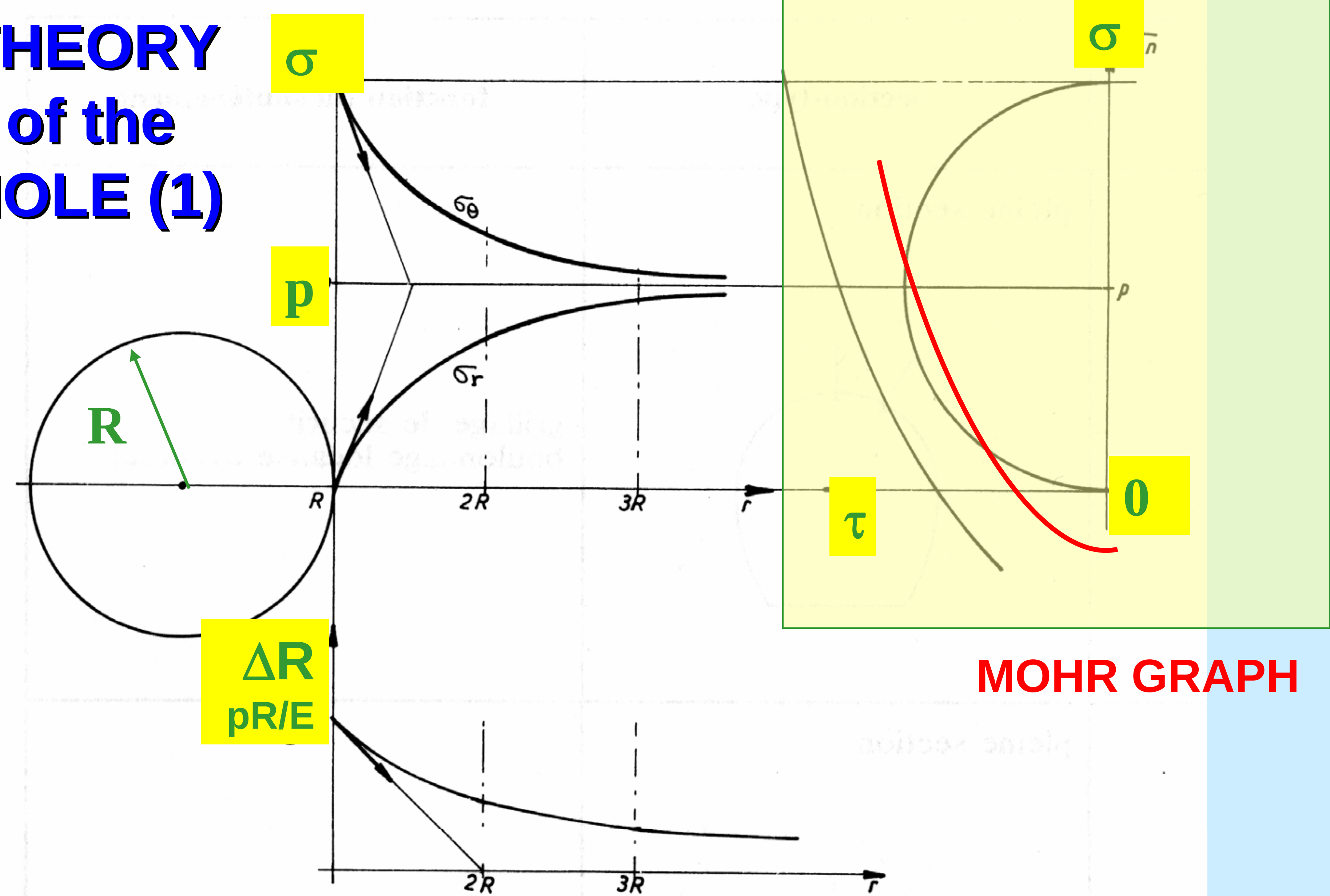
PART 3

theory of the hole

inside a highly stressed medium

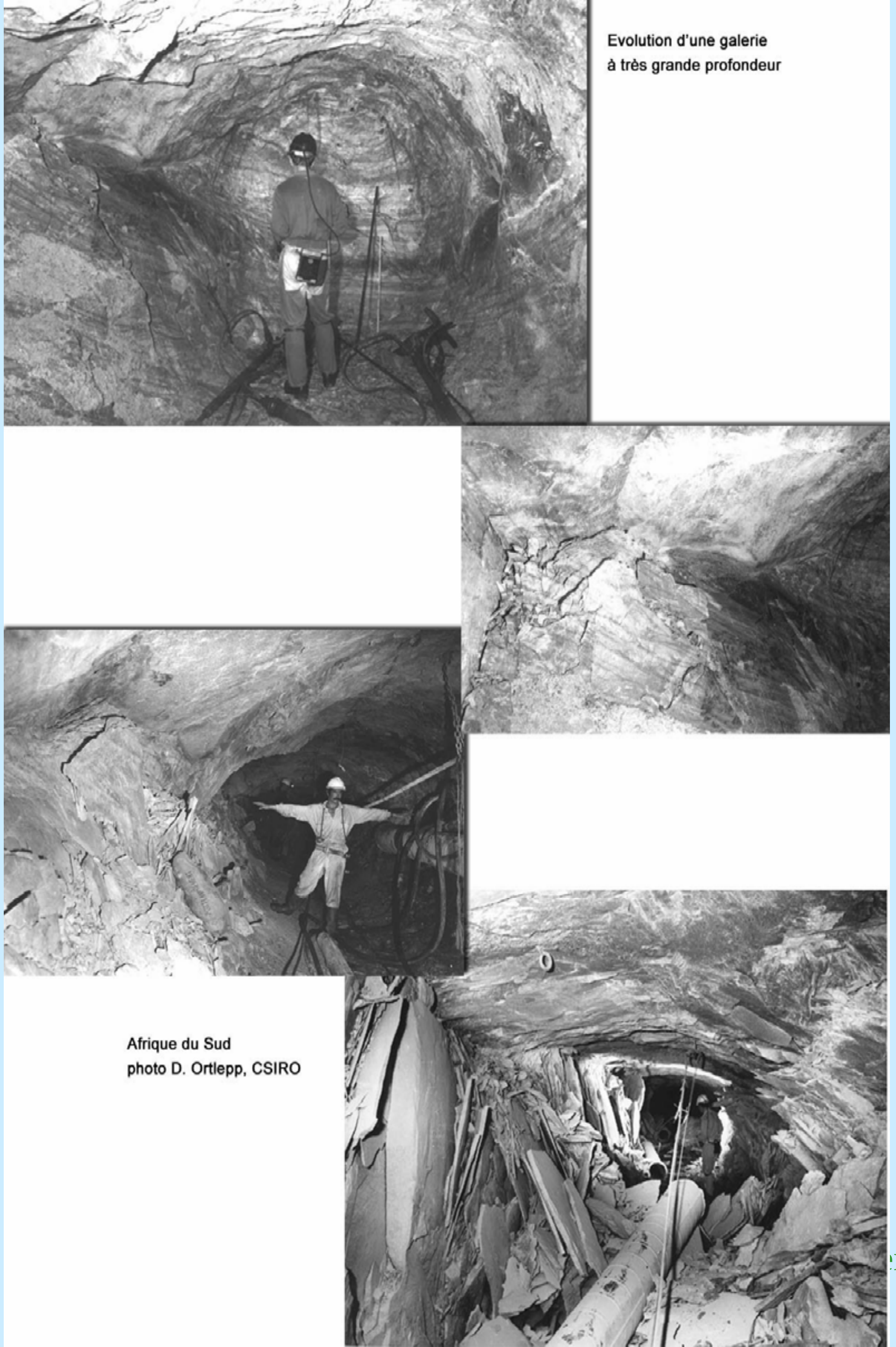
& stress control

THEORY of the HOLE (1)



2D axisymmetric elastic case : stresses around a cylinder (both the stress field p and the medium are isotropic)

ROCK BURSTS AT MONT BLANC TUNNEL & ROCK BOLTS !

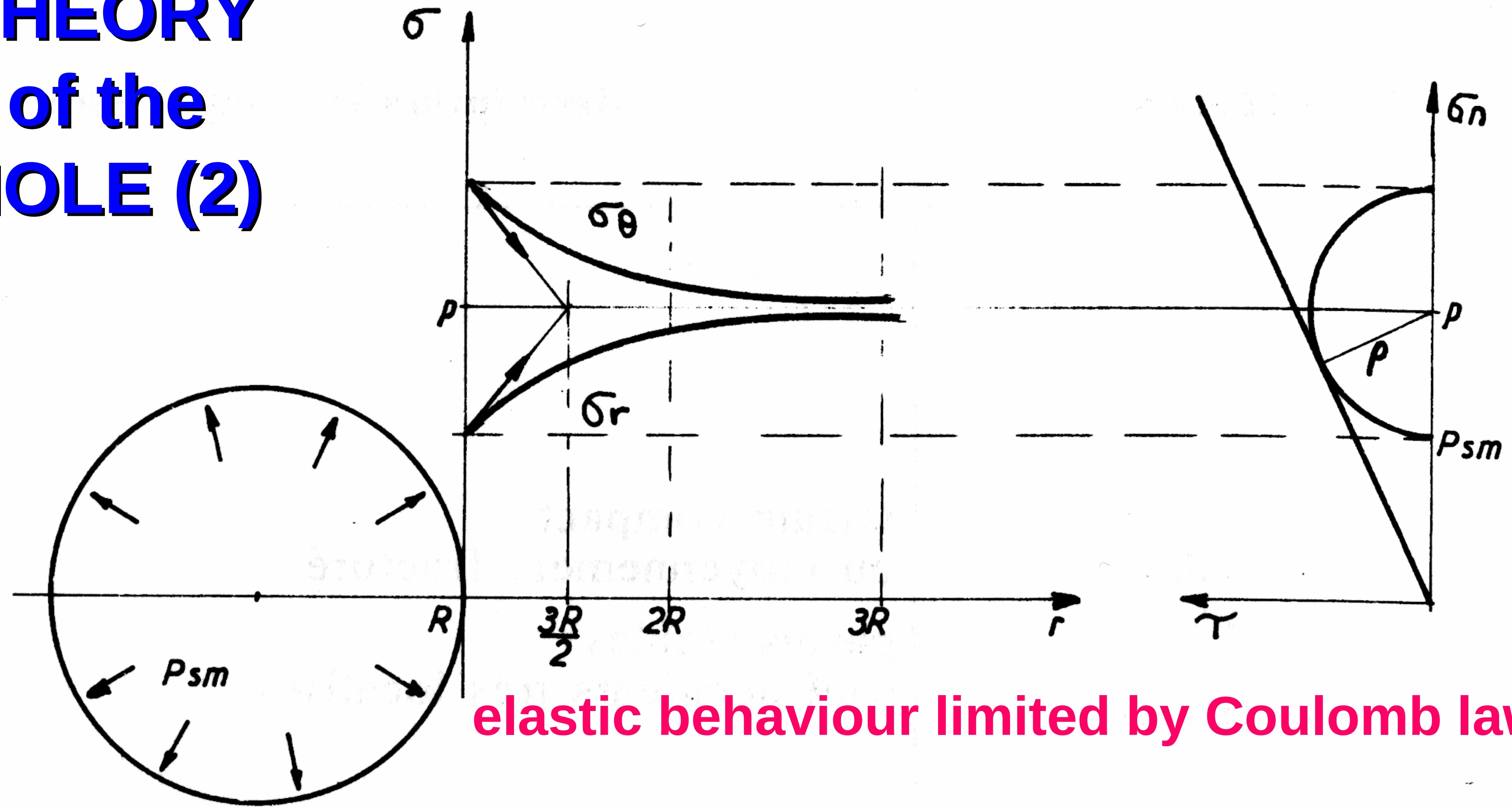


SOUTH AFRICA gold mines

evolution of rock rupture around very deep tunnels (~ 3000 m)

COURTESY Daniel ORTLEPP CSIRO

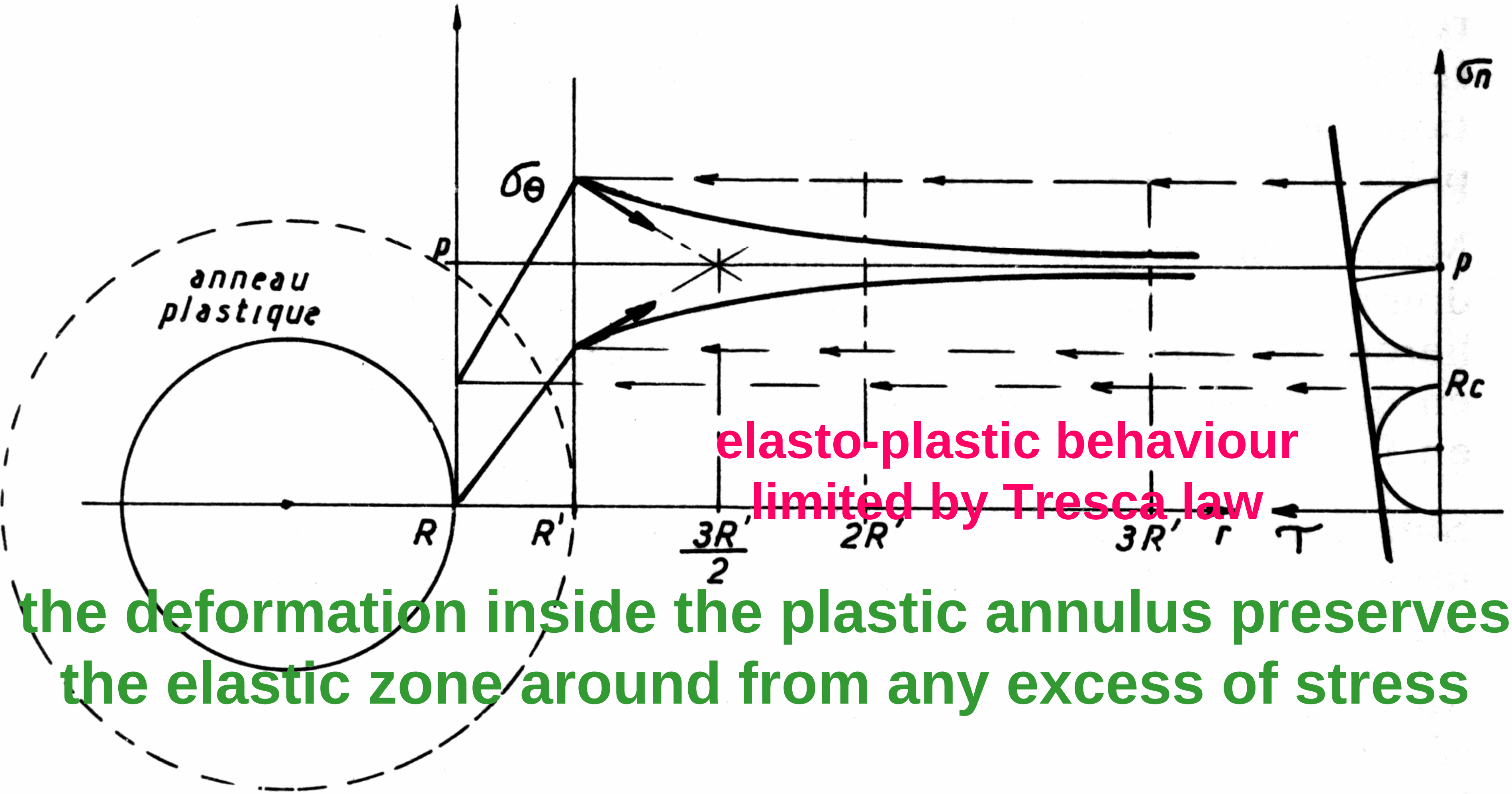
THEORY of the HOLE (2)



elastic behaviour limited by Coulomb law

when the rock strength is too low,
a pressure inside the hole may prevent
the tangential stress to overpass this strength

THEORY of the HOLE (3)



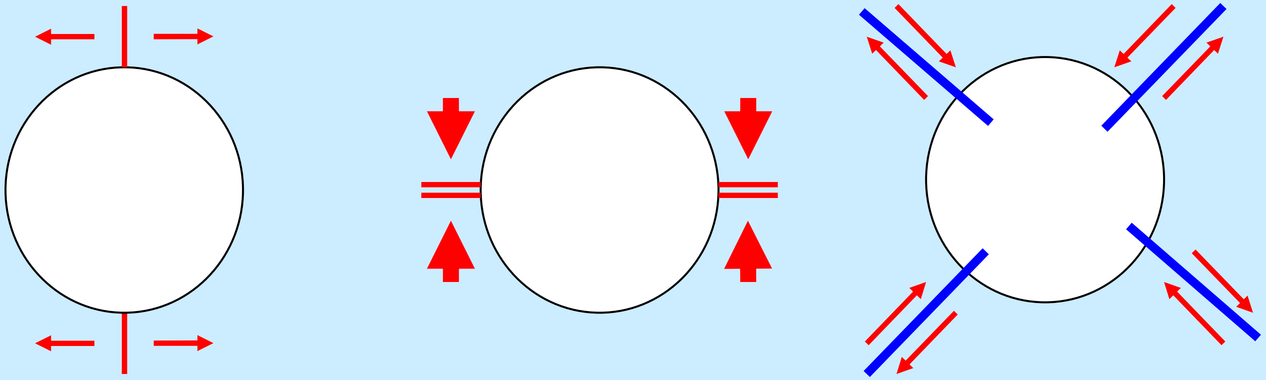
elasto-plastic behaviour limited by Tresca law

the deformation inside the plastic annulus preserves the elastic zone around from any excess of stress

the worksite which taught me how rock behaves around deep tunnels

LANOUX slates behavior under more than 300 m cover

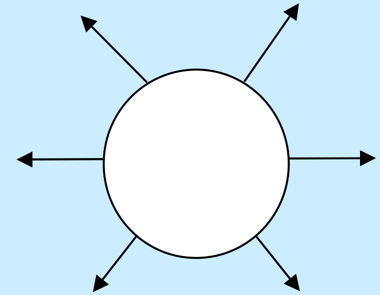
3 mechanisms of self adaptation to any excess of stress

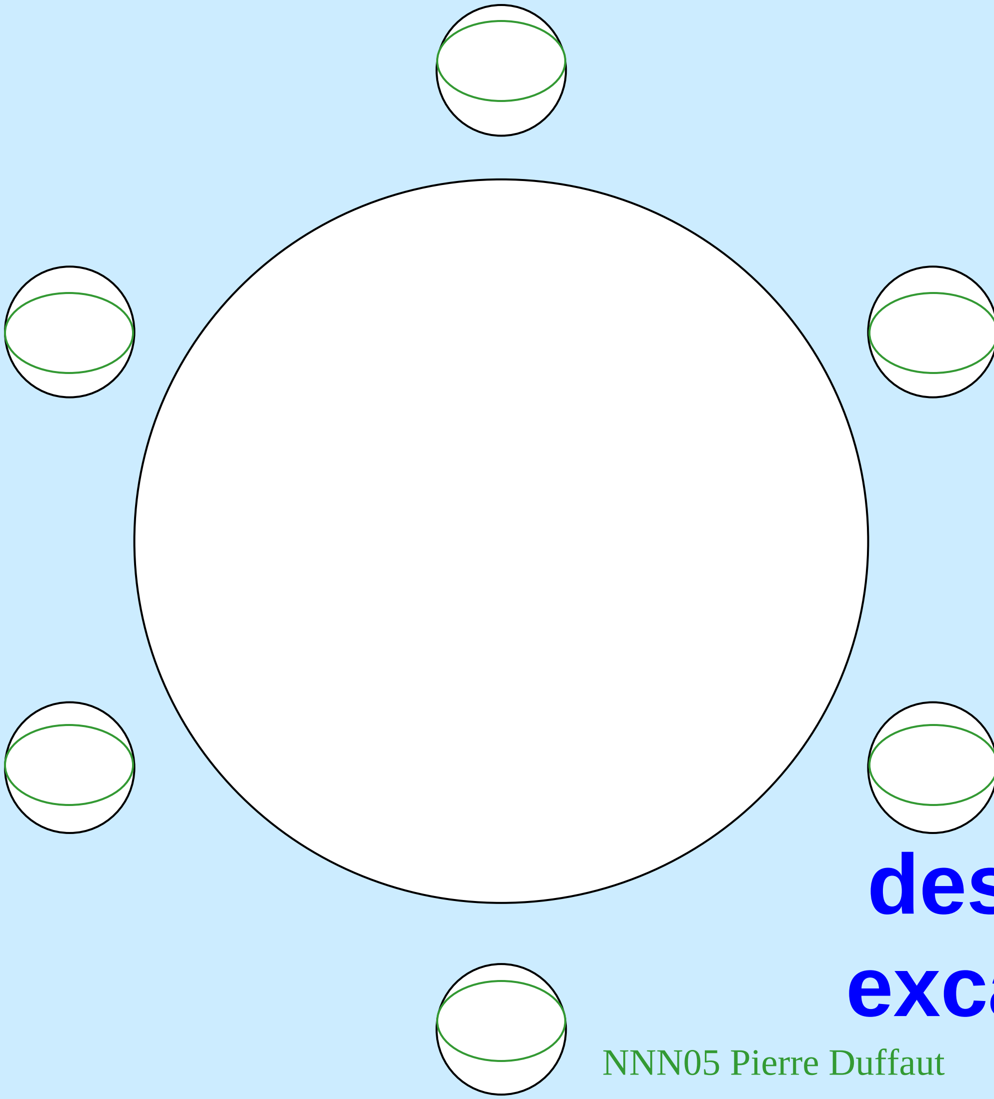


crack opening / squeezing of gouge / slip on joints

rock defects play like built-in safety valves

destressing slots **from** the tunnel

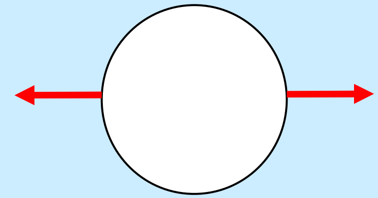




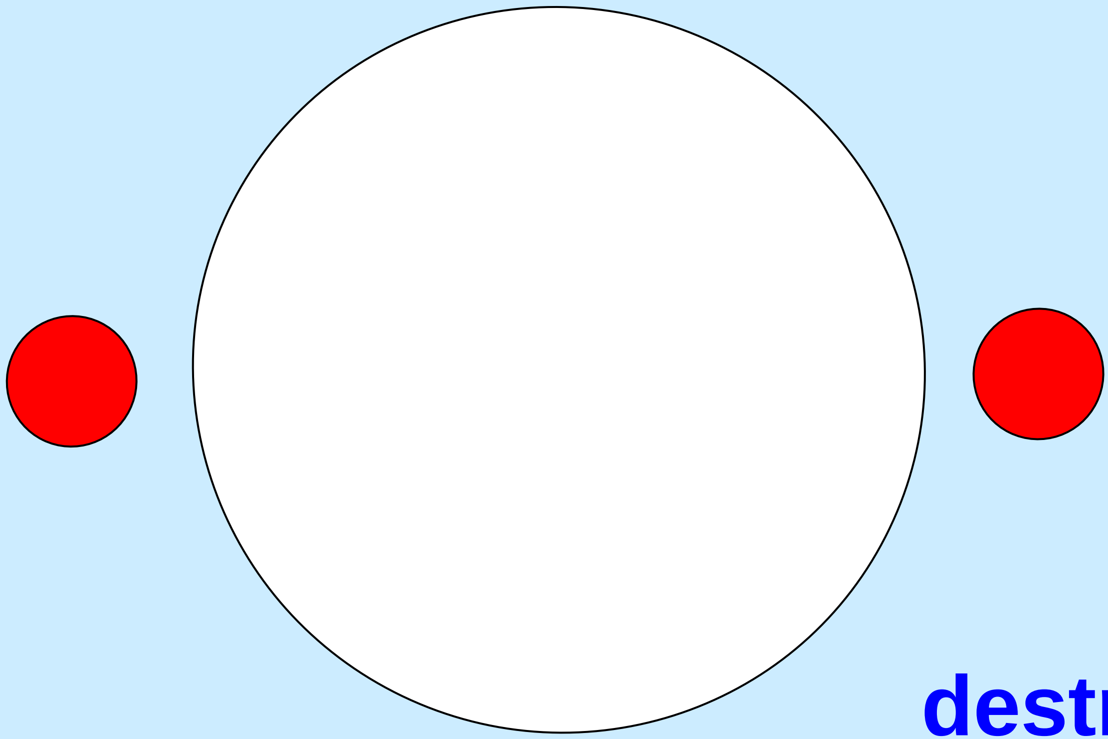
when they close, the stress vanishes

destressing tunnels excavated **before** the main one

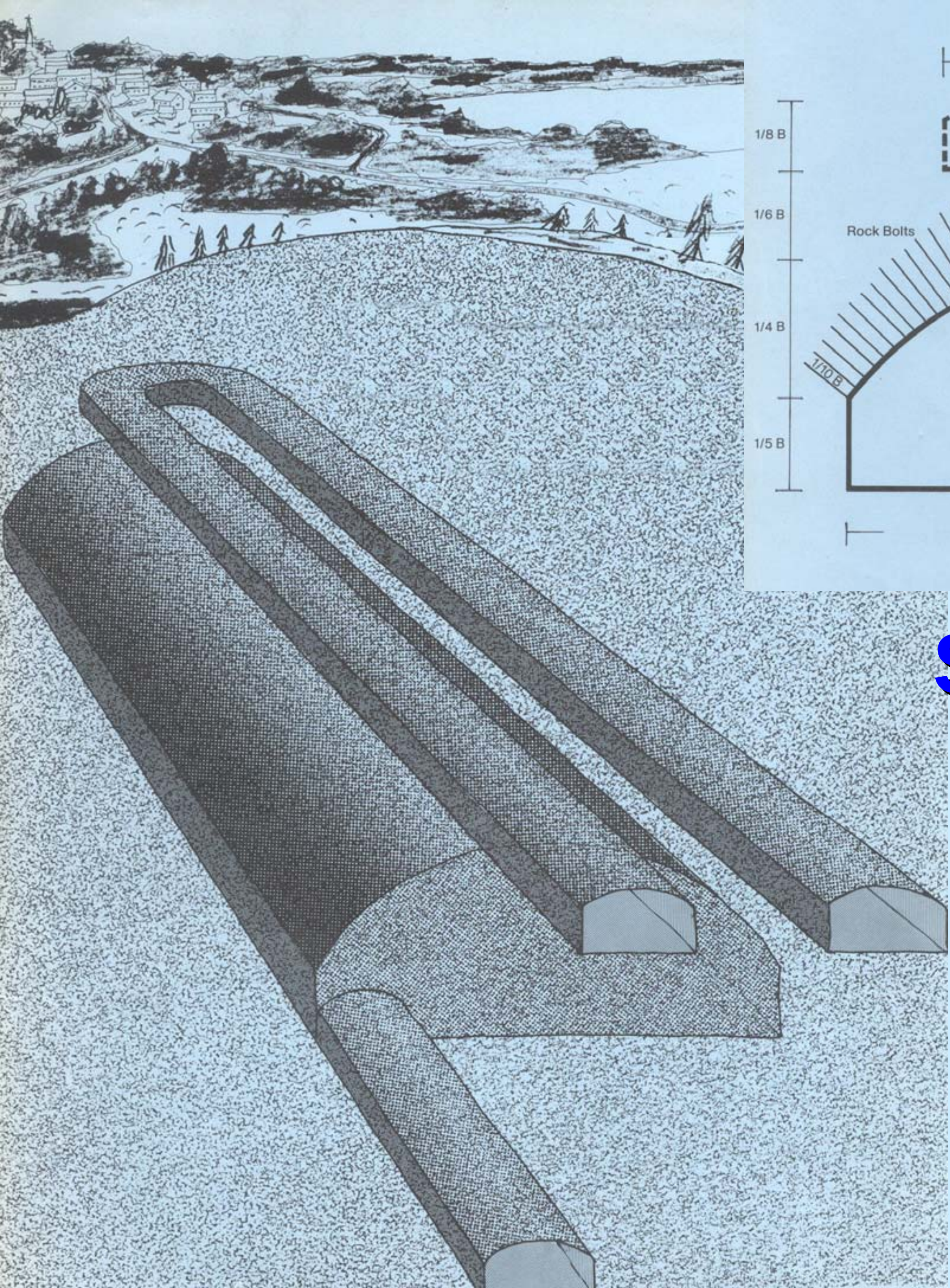
destressing slots from the tunnel

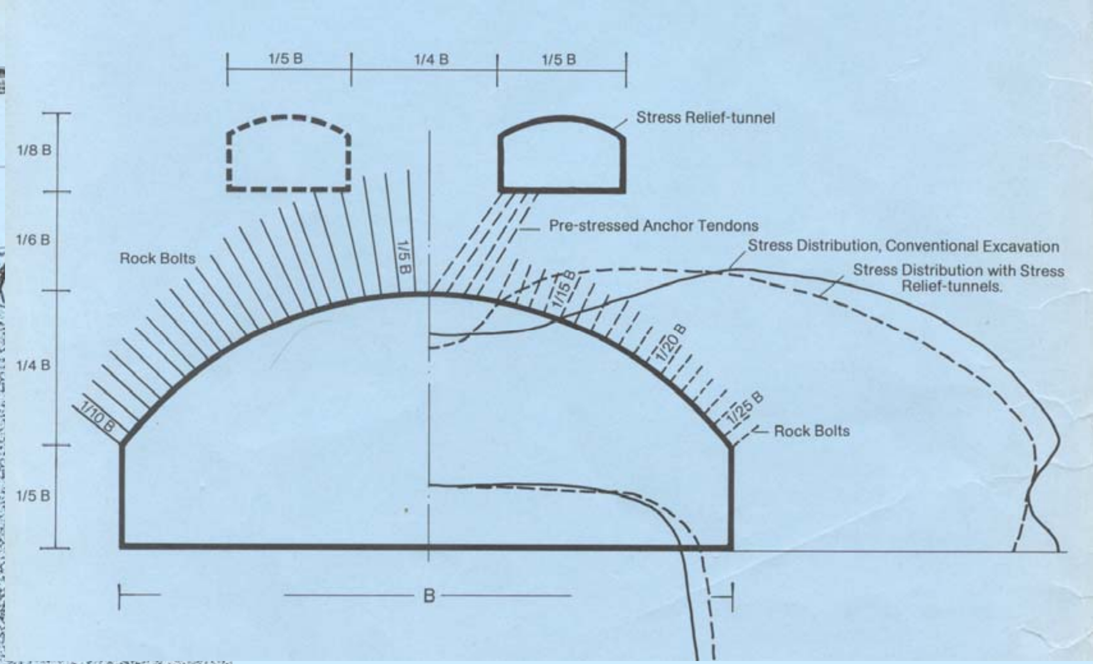


fortunately, any anisotropy, of rock or of stress, will decrease the number of cuts or tunnels from five or six to one pair



destressing tunnels excavated before the main one





STRAIN CONTROL

upper galleries will limit the stresses around the wide vault below (patent SELMER, Norway)

in addition they may host cable anchorages

PART 4

some conclusions for a billion litres (megaton) chamber

TINDAYA MONTAÑA

FUERTEVENTURA ISLAND

CANARY PROVINCE, SPAIN

E. CHILLIDA SCULPTURE

CLOSE TO A CUBE 45-50-60 m

- one ACCESS GALLERY towards horizon
- two SHAFTS (towards sun and moon)

ARUP PROJECT, to begin 2007

underground works are unrecognized & underrated

contrary to bridges and other prestigious buildings,

- they are "built" out of view of passers-by,
- they don’t appear in the built landscape,
- for long they did not rely on accurate calculations,
- they do not glorify their owners,
- neither any professionals involved, be architects, engineering bureaus, contractors, and so and so

underground works are unrecognized & underrated

when conditions get tough,
the civil engineering community
doesn’t understand underground works

only mining people can tackle them

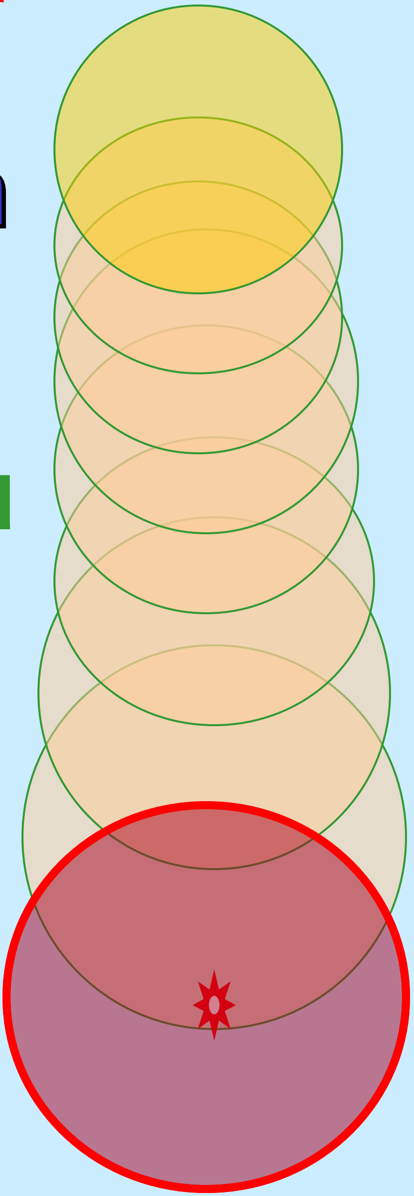
the cheapest and fastest way for
a billion litres cavern is

a nuclear explosion

within a tenth of a second
a spherical cavern is formed

which will evolve into a kind
of chimney and leave a void
cylindrical cavern

over a melt rock lake filled
with collapsed debris



in order to
obtain a
megaton
volume

a 100 kiloton
bomb would
be needed

I don't think
it is yet
serious

from Underground nuclear testing in French Polynesia, 1999

LAST DIA

conclusions for a billion litres cavern

- multiple caverns would call for very wide spacing
- even so, excavating the next one would be very dangerous for the stability of the first ones
- horizontal caverns are very sensitive to rock & stress anisotropy (one direction only permitted)
- many suppose that granite-like rocks are the best ones
- deformation of schistose rocks, such as Fréjus rocks, could assist destressing before excavation
- a megaton cavern at Fréjus is an impressing challenge

I would like helping you master it

THANK YOU

La Liberté, lightening the MEGATON cavern